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Assessment of Local Excavation Support Systems: A Case Study of Nablus City, Palestine

تقييم أنظمة دعم الحفريات المحلية: حالة دراسية لمدينة نابلس، فلسطين

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Abstract

Excavations of soil and rock are one of the most important elements in laying the subsurface structures. These excavations usually require excavation support systems that have fundamental influence on the safety, profitability, speed and quality of construction projects. Despite the great importance of the support systems, most designers and contractors know very little about their design and construction and they rely heavily on experience. The goal of this paper is to present a review of excavation support systems available worldwide and to survey the current state of practice in the local area (Nablus - Palestine), including available types, reasons for failure, and methods of design and construction of excavation support systems. This paper also suggested new techniques that may be adopted locally as an excavation support system. Conclusions of this study are presented and recommendations are suggested to identify what research and development should be carried out to improve the process of design and construction of excavation support systems.

Key Words: Excavations, Excavation Support Systems, Soil Nailing, Nablus – Palestine.

ملخص

الحفريات في التربة أو الصخر هي من أهم عناصر بناء المنشآت تحت سطح الأرض. إن هذه الحفريات بحاجة إلى نظام دعم مناسب؛ لأنه مهم للأمان في الموقع إضافة إلى الربح والسرعة ونوعية البناء. بالرغم من أهمية هذه العملية إلا أن معظم المصممين والمقاولين لا يعرفون إلا القليل عن تصميمها وتنفيذها ويعتمدون بشكل أساسي على الخبرة السابقة. ويمكن إجمال الهدف من هذه الدراسة في إعطاء صورة ملخصة عن أنظمة الدعم المتوافرة عالميا ومسح إحصائي لأنواع الدعم المتوافرة محليا (نابلس، فلسطين)، متضمنا أسباب الانهيارات وطرق التصميم. وتقترح هذه الورقة أيضا استخدام طرق حديثة وجديدة لدعم الحفريات محليا والاستنتاجات والتوصيات اللازمة للنهوض بعملية دعم الحفريات محليا.

1. Introduction

In some cases, construction work requires ground excavation with vertical or near vertical cuts. The faces of the cuts need to be protected by temporary bracing systems to minimize the excavation area, to keep the sides of deep excavations stable, and to ensure that movements will not cause damage to neighboring structures or to utilities in the surrounding ground. Furthermore, excavation support is an issue of extreme importance to construction safety due to the serious threat to life posed by a potential earth collapse, in addition to their fundamental influence on profitability, speed, and quality of construction projects. Hence, the excavation is one of the most important elements in laying the subsurface structures and comprehends not only all kinds of difficulties, but it also requires most of the means and times for erecting a structure. Despite the great importance of excavation support systems, most designers and contractors know very little about their design and construction, and they rely heavily on experience.

Several design solutions exist for the problem of excavation support[1-7]. These solutions will be categorized and explained in this paper. In addition to that a survey of the common practice methods of excavation support systems and identification of the problems associated

with local excavation systems are presented. Conclusions and recommendations are suggested to improve and develop the local excavation support systems. This study was carried out in Nablus city, in the West-Bank of Palestine, and can be applied to the rest of the West-Bank of Palestine, due to similarity of soil strata and techniques available for constructing excavation support systems.

2. Importance and Objectives of the Study

Many problems occurred in the last few years during excavation below ground surface for subsurface construction in Nablus City, in the West-Bank of Palestine. Problems associated with excavations included loss of lives or severe injuries, losses in properties adjacent to excavations, damages of main streets, partial damages in adjacent buildings, and failure in water, sewage, electricity, and telephone lines. In one case, two persons were killed and three were injured, while in another case, one person was killed and three were injured.

Many questions have been raised up which need explanations and clarification to assess the local excavation support systems. Such questions are:

a. Are there specific design procedures and construction methods to be followed locally for subsurface excavations support?

b. Do we need to develop a local code for excavation support systems that includes design procedures, safety precautions, construction procedures, pre and post construction follow up?

c. Are safety precautions considered when constructing excavations?

d. Is a new technique for excavation support system necessary or our local area and could we adopt one?

The main objective of this paper is to address the above listed questions and try to find answers through surveying and studying several excavations and excavation support systems in the area of Nablus in the West-Bank of Palestine. It is important to note that this study may be

generalized for all West Bank Areas due to similarity in soil strata and design and construction of subsurface excavation support systems.

3. Methodology

The methodology used to fulfill the above objectives was:

a. Literature review of worldwide excavation support system techniques;

b. Survey of local excavation support system techniques used at several sites (more than 40) during the last 10 (1994-2004) years for different types of soil strata in Nablus;

c. Survey of the problems that occurred during subsurface excavation; and,

d. Assessment of the ability to adopt new excavation support techniques.

4. Summary State of the Art Practice of Excavation Support Systems

Two main types of excavations are available: **open excavation and braced excavation.** Open excavations do not require bracing to support the soil. The soil is cut to the steepest slope at which it will safely stand by having the excavation sloped back to the acceptable angle of repose. It is usually 3.0 horizontal to 2.0 vertical for sandy soils, and steeper slopes for shallow excavations in stiff clay or decomposed rock (5).

When it is uneconomical, illegal, or impossible to use open excavations, bracing is employed to support the soil. Many bracing systems are available, the most common are **soldier beams**, which are made of steel or timber that is driven into the ground before excavation. As excavation proceeds, lagging (horizontal timber planks) are placed between soldier beams, then whales and struts (horizontal steel or timber beams) are installed. For wide excavations rakers, which are inclined steel or timber beams, are installed after excavation reaches the desired depth (6-7). **Sheet Piles** are usually driven deeper than the final depth of

the excavation before the excavation is started. Whales and struts (horizontal steel beams) are installed after excavation reaches the desired depth. This is mainly done for trench and narrow excavations. For wide excavation and according to the loading and structural condition, either cantilever or anchored sheet piles are used [8-9]. **Slurry-Walls** are continuous concrete walls that are built beneath ground level before an excavation takes place. They are expensive and complicated structures to build. However, they may be necessary where site conditions do not allow driving of sheet piles or soldier beams [10-11]. **Bored Cast-in-Place Sheet Pile wall,** simply bored-pile can be installed in almost any site and ground conditions and for situations where headroom limitations prevent the driving of steel sheet piles or when it is necessary to avoid vibrations from pile driving. Bored pile can also be used in ground containing boulders that would split steel sheet piles or cause them to come out of interlock [12-13]. **Cofferdam** is a temporary structure built to enclose a foundation excavation with dense walls to exclude the influx of soil and/or water from the excavation, so that a foundation may be laid there in the dry. Cofferdam may be constructed by driving steel sheet piles or driving piles and in some cases installing row of bored and cast in-situ piles [14-15]. **Soil Nailing** is classified as an internally supported system by placing reinforcements in and through the potential failure mass of the soil, while conventional excavation support systems must withstand earth pressures with external structural walls [3,16]. **Soil Grouting**, as soil nailing is a new excavation support system that is gaining acceptance worldwide. There are several varieties of soil grouting, all dealing with the addition of high strength grout to stabilize soil masses. Jet grouting is the technique most commonly used in the support of excavations. This method displaces soil and forms impervious solid columns to help support an excavation[17]. **Soil Freezing** is an innovative technique that utilizes refrigeration pipes to effectively freeze the soil into one solid stable mass. In cold climates and in situations where only short-term excavation support is required, soil freezing is a feasible option. The other important benefit of soil freezing is its ability to halt the flow of ground water, i.e. works like dewatering system[18].

Other Related Works to Excavation Support Systems are **Dewatering** which becomes an issue any time an excavation will proceed below the ground water table. Two basic solutions are available for ground water control [(15)]. **Underpinning** is an additional consideration that often affects the excavation support process. Underpinning becomes an issue when an excavation occurs near an adjacent structure [(14)]. **Stability of Bottom of Excavation,** excavation in clayey soils may cause the bottom of excavation unstable by bottom heaving [(19-20)]. Stability may be increased by increasing the penetration depth of the sheet piles. In addition, stability of the bottom of the excavation in sand, when water table is encountered, may be checked [(15)].

5. Survey of Local Excavation Support Systems

In order to understand the current practice in design and construction of excavation support structures, it is necessary to obtain input data from constructed excavation support systems in our region through surveying projects that have deep excavation (greater than 6 meters). Therefore, 40 projects in Nablus City that had deep excavation greater than 6 m cuts in the last 10 years were reviewed and taken into consideration in the survey. The data was collected by the researcher through several visits to the sites during the construction period. The goals of the survey were to determine the current state of practice in design and construction of excavation support systems, identify causes of failure among existing projects, availability and sources of technical guidance, ability to adopt new techniques for excavation support systems, and to identify what research and development should be carried out in the area of excavation support design and construction in the region.

Two main strata exist in the West-Bank according to geotechnical point of view. The first stratum is weathered fragmented and mainly heavily jointed limestone bedrock of medium to weak strength. The unconfined compressive strength of such rock ranges between 20,000 kN/m^2 to 60,000 kN/m^2. Sometimes the bedrock is observed on the ground surface (especially in mountainous areas) but in most cases it is covered by silty clay soil. The second stratum is sedimentary soils of

brownish to reddish and in other cases, blackish silty clay of high plasticity or residual soils from weathering of limestone which is white to yellowish silty clay of low plasticity (marl soil) with boulders and blocks of rocks of varying sizes. The consistency of silty clay soil is mainly stiff to very stiff soil. The unconfined compressive strength of such soils ranges between 150 kN/m^2 to 300 kN/m^2. The sitly clay soil layer always overlies the limestone bedrock layer and has a thickness that ranges from few meters up to about 30 meters as a maximum depth found in some areas, mainly valleys and low areas.

5.1 Types of Locally Available Excavation Support Systems

The data collected through the survey shows that there are four common methods available locally for excavation support, which are:

a. Open Cuts

Most local projects that required deep excavation are unsupported and left as open cuts. The open cut is usually vertical without any support system and is mainly in weathered fragmented limestone and in silty clay soils. Occasionally, sloping sites are provided depending on the spaces available, but inside the urban area, where this study was carried out, there was no space for sloped open cut.

This method is simple, cheap, and requires no specialized personnel. On the other side, severe problems occurred due to failure in the cuts which led to loss of lives, injuries, failure of utility lines, and damages to nearby properties such as roads, structures, etc. For this reason, in this study, excavations that have open cut are considered unsupported excavation.

b. Gravity and Semi-Gravity Retaining Walls

This is considered as one of the methods for bracing deep excavation in our region. It is mainly established by constructing successive heavily reinforced retaining walls in very short period of time, either for the entire excavation or for selected sides. In addition, they may be constructed for the entire width or constructed by segments (slices).

This method is not fully guaranteed, especially when existing heavy structures surround the excavated site. Moreover, dangerous problems may occur during excavation and construction of retaining walls such as failure of existing roads, or nearby structures. Such problems were observed even in summer seasons when rainfall does not exist. Another disadvantage of this method is that it will reduce the area of the site due to the large width of the retaining wall especially at the bottom. This type of excavation support system always integrates into the structure itself. Figure 1 shows an example of excavation support system by gravity retaining wall.

c. Cantilever Retaining Walls

Cantilever retaining walls may be used instead of gravity retaining walls and considered the most common one. They are constructed and used exactly in the same manner as in gravity retaining walls. However, they are used when type of soils are shown to be stable and allow workers to construct the wall without any danger. Sometimes blocks of rocks are used to stabilize the cut and allow the worker to construct the wall in safer environment. In this case, the system becomes very expensive. This type of excavation support system always integrates into the structure itself. Figure 2 shows an example of cantilever retaining wall as a bracing system, and Figure 3 shows an example of using blocks of rock for stabilizing the side before constructing retaining walls.

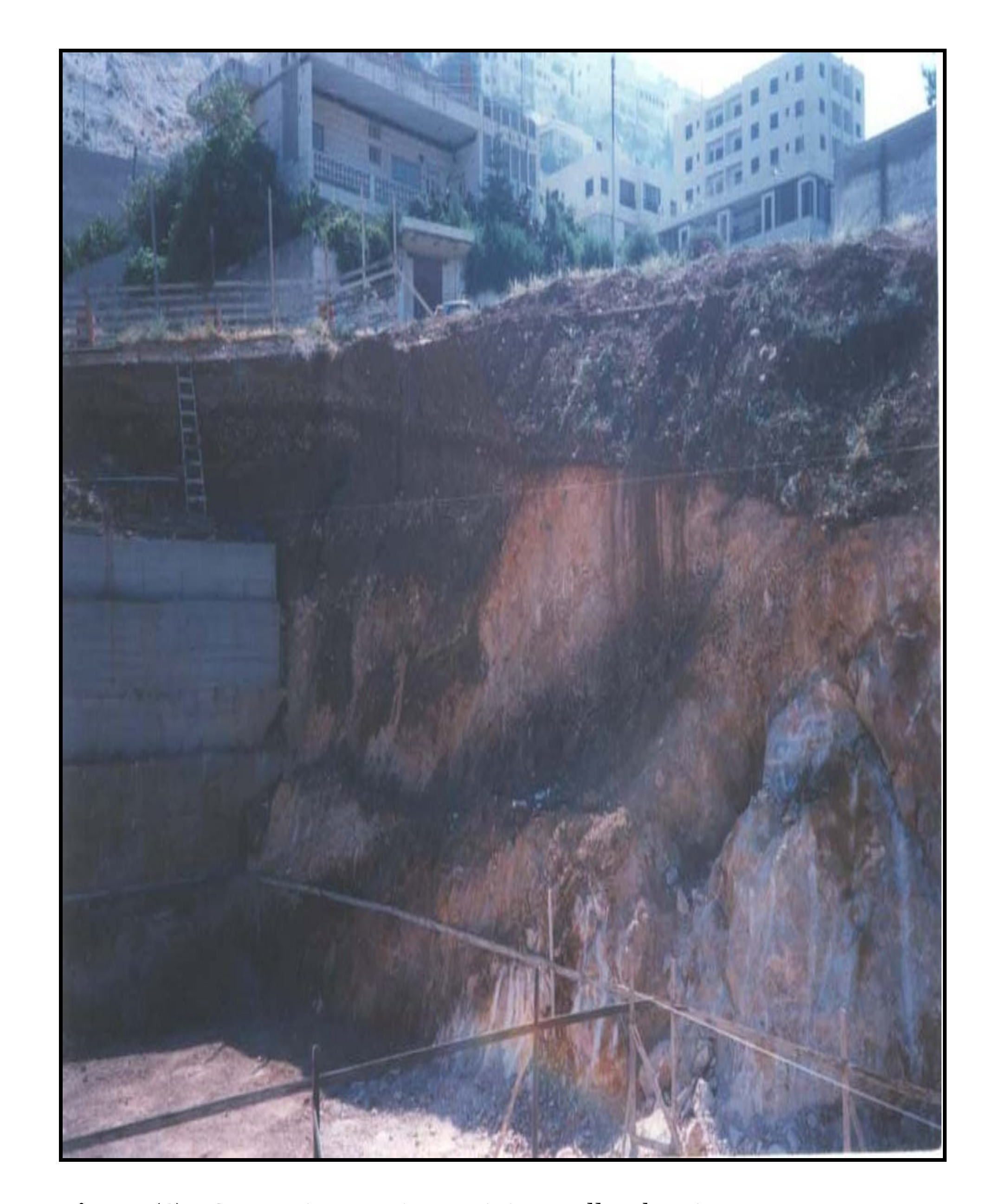


Figure (1): Successive gravity retaining wall as bracing system



Figure (2): Successive cantilever retaining wall as bracing system

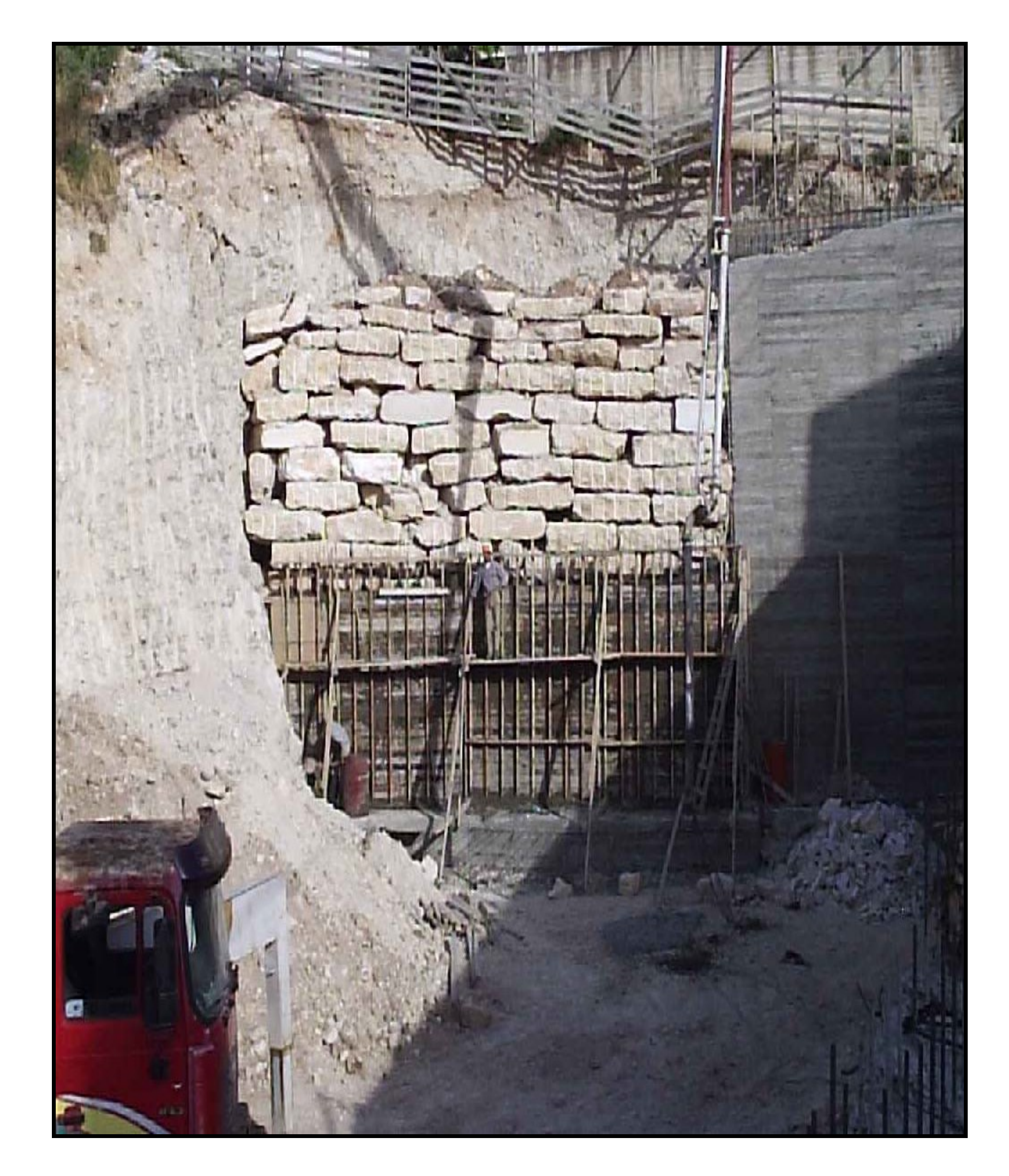


Figure (3): Blocks of rock use to stabilize the cut before constructing retaining wall

d. Bored Cast in-situ Piles

Row of bored cast in-situ reinforced concrete piles as excavation support systems are used in our region. This type of support system is very expensive, and for this reason, it is considered as the last solution. The piles are made of reinforced concrete, bored, and cast before the excavation starts. This system is mainly used when buildings or main streets exist close to the site. It is considered as the safer method available among local excavation support systems; however, it is very expensive. Figure 4 shows an example of this type of bracing excavations. Table 1 presents summary of the available excavation support systems with their advantages and disadvantages.



Figure (4): Bored cast in-site reinforced sheet piles as bracing system**.**

Table (1): Summary of available excavation support systems with their advantages and disadvantages.

Type of local excavation support system	Advantages	Disadvantages
Open Cut	- Cheap - Simple - Requires no specialized personnel	- Requires large area for sloping back - For small height less than 6 m - Not possible in urban areas
Gravity Retaining Wall	- Locally available - Required no specialized personnel	- Time consuming - Danger threat to workers and surrounding structures - Reduce the area of the building due to large width at the bottom - Expensive
Cantilever Retaining Wall	- Locally available - Required no specialized personnel	- Time consuming - Danger threat to workers and surrounding structures - Reduce the area of the building due to large width at the bottom - Expensive
Cantilever Retaining Wall with Blocks of Rock behind it	Locally available	- Time consuming - Danger threat to workers and surrounding structures - Reduces the area of the building to some degree - Requires specialized personnel - Very expensive

… Continue table (1)

Type of local excavation support system	**Advantages**	**Disadvantages**
Bored Cast in-situ Sheet Piles	- Locally available - Safe - Size of the building will not be affected - The only method available for some cases	- Requires specialized equipment - Requires specialized personnel - Very expensive

5.2 Results of the Survey

Since the main strata in the West-Bank of Palestine are silty clay soils and limestone rocks, and almost all excavations are done in these two strata. The surveyed projects in Nablus City were carried out in these two types of strata. Through randomly selected projects, it was found out that 55% (22 out of 40) of the projects in the survey that have deep excavations were excavated in silty clay soils while 45% (18 out of 40) were excavated in limestone rocks.

Table 2 shows the general trends regarding excavation in all sites surveyed, i.e. in both silty clay and limestone excavated sites. The results of the survey show that 73% of all projects, for both silty clay soils and rocks -which have deep excavation- have no excavation support systems, i.e. sides of excavation are left unsupported (open cuts). Also, this table shows that, in general, 20% of all projects that had no excavation support system had problems. However, 48% of all projects should implement support system at the end.

Table (2): General trends regarding availability of excavation support systems for all surveyed excavations (for both Silty Clay and Limestone Rock)

Availability of Excavation Support Systems*	**No. of Sites Surveyed**	**Percentages**
Total excavations of the survey	40	
Excavations without Support Systems	29	73%
Excavations with Support Systems	11	27%
Failure in excavations (excavation initially without support systems that had to provide support system after excavation due to problems occurred)	8	20% of all sites
		28% of sites that have initially no support system
Excavations that have support systems at the end (initially with or without support system)	19	48%

* Note: in this study, excavations that had open cut were considered as excavations without support systems.

Regarding excavations and support systems in silty clay soils, the survey shows (as presented in Table 3), that 86% of projects in silty clay soils should implement support systems. However, only 50% of all projects in silty clay soils have initially excavation support systems.

Table (3): General trends regarding excavation support systems in Silty Clay Soils only

<table>
<tr><th>Availability of Excavation Support Systems</th><th>No. of Sites Surveyed</th><th>Percentages</th></tr>
<tr><td>Total sites</td><td>22</td><td></td></tr>
<tr><td>Excavations with Support Systems</td><td>11</td><td>50%</td></tr>
<tr><td>Excavations without Support Systems</td><td>11</td><td>50%</td></tr>
<tr><td rowspan="2">Failure in excavations (excavation without support systems that had problems and had to provide support system after excavation)</td><td rowspan="2">8</td><td>73% of excavations that have initially no support system</td></tr>
<tr><td>36% of all excavations in silty clay</td></tr>
<tr><td>Excavations that have support systems at the end (initially with or without support system)</td><td>19</td><td>86%</td></tr>
</table>

Table 4 shows the result of survey regarding excavations and support systems in rocks, in which no support system was provided. Only 17% of projects that had deep excavations in rocks had problems, mainly minor type problems, such as, falling of blocks of rock or erosion of clay that fill cavities within the rock layer. Usually, deep excavations in rocks have no support systems, and actually, they do not need any support system; however, they require attention during excavation.

Table (4): General trends regarding excavation support systems in Rocks (Marlstone and Limestone)

Availability of Excavation Support Systems	**No. of sites Surveyed**	**Percentages**
Total sites	18	
Excavations with Support Systems	0	0%
Excavations without Support Systems	18	100%
Excavations without support systems that had problems (minor problems)	3	17%
Excavations without support systems that had no problems	15	83%

Regarding types used (Table 5), the survey shows that 74% of the projects that had excavation support systems had retaining walls (gravity or semi-gravity or cantilever). The rest (26%) had sheet piles (bored cast in-situ reinforced concrete). Cost was the most important reason for selecting types of excavation support systems.

Table (5): General trends regarding types of designed excavation support systems

Type of Excavation Support Systems	**No. of sites Surveyed**	**Percentages**
Total sites that have support system	19	
Retaining Walls (Gravity, Semi-Gravity, or Cantilever)	14	74%
Sheet Pile Walls (Rows of bored cast in-situ piles)	5	26%

5.3 Causes of Failure in Local Excavations

The survey indicated that most failures in the study area occurred in open cut (8 out of 40), i.e., where excavation is left unsupported, especially in silty clay soils. It was occurred in winter as well as in summer. The main cause of failure is the loss of cohesion in the soil due to drying or wetting. Wetting may be due to surface water from rainfall or leakage from sewer or water pipelines. Sometime, loads near the cut cause failure, such as traffic loads and structural imposed loads. Problems in excavations in limestone rock were mainly due to sliding of blocks of rock. Other problems occurred due to failure of silty clay soil that fills joints or cavities in rock layer. Bored cast in-situ piles worked excellent and had no problem at all, except in one case where the penetration depth was not adequate (design problem).

5.4 Design of Local Excavation Support Systems

The collected data indicated that there were no design procedures or specific guidelines for the construction of excavation support systems as temporary structures. However, most designers tended to rely on their experience and used common methods of design procedures for excavation support as permanent structures, like retaining walls and sheet piles. Codes and project specifications simply required the designer to provide safe access and support for excavations.

Open cuts had no design procedures and designers mainly gamble on the cohesion of the soil which is very erratic. Sometimes (unfortunately) the planning of the excavation was left to the superintendent or even to a shovel operator.

Gravity, semi-gravity and cantilever retaining walls are designed based on the general guidelines for retaining wall. Sometimes, blocks of rock are used to support the excavation before starting the construction of the retaining wall. This is to increase the stability of the cut and to prevent falling of soil.

Bored cast in-situ sheet pile walls have no specific design procedure. Common practice is installing pile on and pile off. The author designed

sheet pile of bored cast in-situ reinforced concrete using classical design procedure of sheet piles. It is worth mentioning that finite element analysis is sometimes used for designing this type of support system. However, it is not a practical design procedure as much as it is used for feed back analysis of designed systems or for developing the design procedure.

5.5 Conclusions of the Survey

The main conclusions of the survey are as follows:

* It is most likely to have problems in excavation in silty clay soils; hence, support system should be implemented.
* Excavation in rocks may have minor problems that need only awareness without support system.
* It can be concluded that the system of excavation support is not available in the West-Bank in general and in Nablus City in particular.
* There is a necessity for adopting new, simple, and cheap excavation support system.

6. Suggested New Types for Local Excavation Support Systems

Typical excavation support systems available locally are retaining walls and bored cast in-situ sheet piles. These methods were discussed earlier and proved to have problems regarding construction and cost, especially for high excavations. In this section a new excavation support system is suggested to be adopted for the West-Bank in general and Nablus City in particular, which has never been used locally. The suggested new method for excavation support is soil nailing. This method has been well developed and being used in all over the world and shown to be working excellent especially for silty clay soils and rocks like the case in our local area. This method is the most applicable and suitable method that may be adopted to support deep excavation in our area. Table 6 below discusses the applicability of common worldwide excavation support methods and the reason behind suggesting soil nailing to be adopted locally.

Table (6): Common types of excavation support systems and their applicability to our local project

No.	Type of Excavation Support System	Applicability	Main Reasons
1	Open cuts	Not Applicable	- Urban areas has no space to slope back
2	Soldier Beam	Not Applicable	- Very difficult to drive beams into our soil (silty clay with boulders and blocks of rocks) - Driving equipments are not available and are very expensive
3	Sheet Piles	Not Applicable	- Same as Soldier Beam
4	Slurry Wall	Not Applicable	- Expensive and require very expensive special equipments
5	Bored Cast-in-Place Sheet Piles	Applicable	- Very expensive
6	Cofferdams	Not Applicable	- Usually for large projects such as dams, power stations, etc.
7	Soil Nailing	May be Applicable	- Simple process and equipments - cheap
8	Soil Grouting	Not Applicable	- Needs high technology
9	Soil Freezing	Not Applicable	- Needs high technology - Weather will not help

Soil nailing, like the other systems described in this paper, is a method of supporting the walls of an excavation. The primary difference between soil nailing and other conventional systems is that soil nailing stabilizes the sides of an excavation through in-situ reinforcement of the soil. Systems such as soldier piles and lagging or slurry walls must withstand earth pressures with external structural walls; while soil nailing stabilizes a soil mass by placing reinforcements in and through the potential failure mass of the soil. For this reason, it is classified as an internally supported system [4]. Soil nailing actually increases the overall shear strength of the soil, restrains its displacements, and limits its decompression [16]. This is accomplished through the use of tension elements that are driven or drilled and grouted into the ground. The reinforced ground becomes the system's primary structural element, with a layer of shotcrete applied to support the face of the soil nailed wall.

6.1 Advantages of Using Soil Nailing

Some of the advantages of soil nailing compared to conventional systems are:

∗ cost saving up to 30% compared to other conventional systems[3];

∗ requires only light equipment, rapid and simple construction techniques, and may be adopted to different site conditions [4];

∗ walls have been constructed to depths of 30 meters using soil nailing[4];

∗ the number of individual nails is so great that failure of one or two is not critical;

∗ nail diameters are small which makes drilling into rocks much easier;

∗ the system is relatively flexible and can withstand some ground movement; allows for the control of surface deflections [16];

∗ soil nailing is top down procedure as opposed to bottom-up process that is used with other support systems like retaining walls [4];

* soil nailing can also be used in the repair and reconstruction of existing structures;
* soil nailing is used for slope stabilization [16];
* in many applications soil nailing can be the least disruptive way to construct a retaining wall;
* soil nailing requires only normal geotechnical knowledge to construct.

6.2 Components of Soil Nailing

As stated previously, in soil nailing the soil is reinforced by passive inclusions or nails, which resist tensile stresses, shear stresses, and bending moments. Nails are generally steel rods or bars of high yield strength from 15 to 46 millimeter in diameter. A continuous shotcrete facing is applied to the outside face of the reinforced soil mass to stabilize the ground between the layers of nails. Each nail is attached to the facing by embedded steel plates, cladding, or other methods [3].

6.3 Construction Process

The basic construction sequence for a soil nailed wall is illustrated in Figure 5. It is a top down process that involves excavation to a specified depth, installation of nails, application of facing, and further excavation. The depth of cut which is permissible before the installation of nails and facing depends on the properties of the soil mass. In some cohesive and rocky soils, cuts of approximately three meters can be made before in-situ wall construction. Less stable soils such as sand can only be excavated to a depth of about 1.5 meters before the installation of the soil nailing. Very unstable soils may require the placement of shotcrete before the nails are installed. Each section or layer excavated and nailed becomes linked to the surrounding sections, and the entire soil mass becomes an interconnected and stable system.

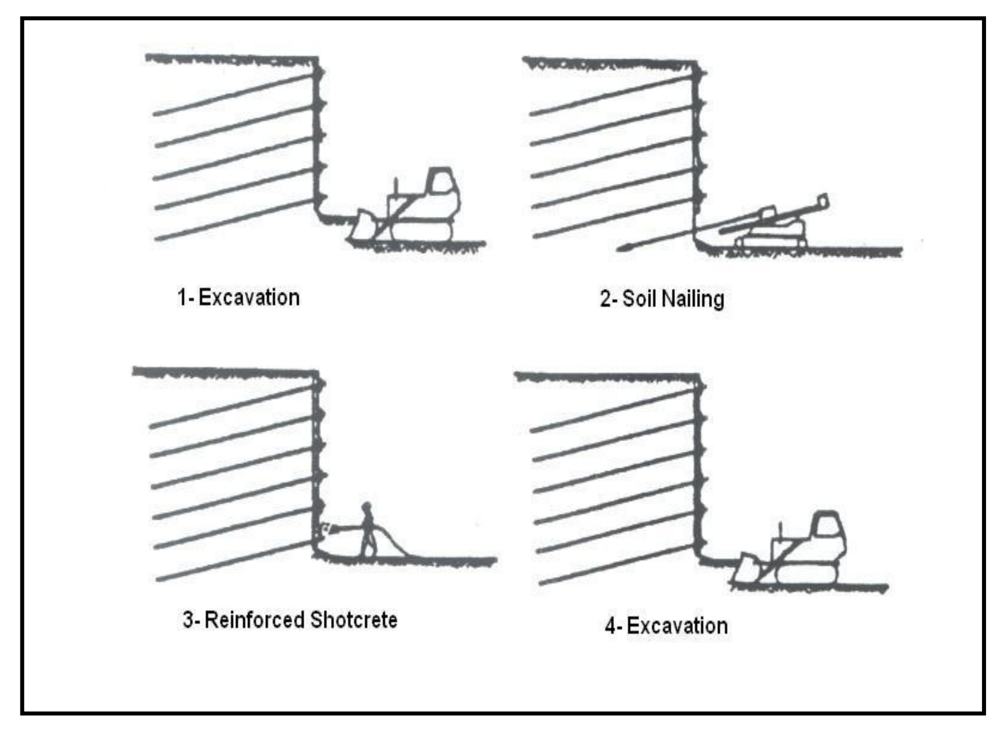


Figure (5): The basic construction sequence for soil nailing [3].

6.4 Design Methods and Available Standards/Guidelines

There are several approaches to design soil nailed retaining structures. Each method has been successful at achieving the design concern to ensure that the soil-nail interaction is effectively mobilized to restrain ground displacements and ensure structural stability with an appropriate factor of safety [4].

It is recommended when adopting soil nailing techniques, as a local excavation support system, to develop our own design method and guideline including construction and inspection manuals. This is because the design and construction depend on local soil parameters, available machines, and their elements.

7. Conclusions and Recommendations for Further Studies

7.1 Conclusions

It is a legal necessity when a new construction is launched in a developed area to provide protection to the excavation itself and to adjacent structures and facilities like buildings, roads, utility lines, etc. Usually, excavation in a new site to any depth may cause loss of bearing capacity, settlement, or lateral movement to existing property. Hence, to avoid these difficulties, one must seek efficient, economic, and available methods of protection for the excavation prior to construction.

The main conclusions of this research are:

* Safety is the most critical issue in designing excavation support systems.
* Cost and technical feasibility are the next most important considerations.
* For locally available equipments and techniques, bored cast in-situ reinforced concrete sheet piles may be the most appropriate for safety requirements. However, they are expensive compared with other excavation support systems.
* Excavations in silty clay soils often create problems due to failure in the excavations themselves.
* Excavation in rocks may cause minor problems that could be overcome without support system.
* The design and supervision of excavation support systems should be assigned to experienced and specialized engineers who are, unfortunately, few in Nablus.
* Adequate soil exploration program is a pre-requisite for any successful excavation support system.

7.2 Recommendations for Further Studies

* It is important to adopt a program for developing technical guidelines for design, construction, and inspection of excavation support systems.

* It is recommended to study the feasibility of adopting new excavation support systems, like soil nailing, which works very well in cohesive soils in most developed countries, provided suitable equipments are available.
* For more accurate analysis of a bracing system, finite element analysis has been used and shown good results. This method has been used in analyzing many projects and the results were compared to actual cases by using instrumentation. This may be done locally providing an appropriate support.

8. References

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